TRANSIENT MAGNETIC FLUX DENSITY MEASUREMENT RESULTS ON A FUSELAGE-LIKE TEST SETUP AND INVESTIGATION OF THE EFFECTS OF APERTURES

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Abstract: Investigation of susceptibility of airborne equipment to high transient magnetic fields was conducted in a high current- and in a high voltage laboratory. Metal test cylinders were subjected to current impulses, up to 15 kA, simulating high surge currents, representing directed energy applications or lightning strokes. The cylinder used in the high current laboratory is made of aluminum and is representative in size and construction of an aircraft fuselage. Surge current measurements, dB/dt measurements outside and inside the test cylinders (B is the magnetic flux density), and the measured effects of apertures (open or closed) are described in the paper.

I. INTRODUCTION

When an aircraft is in flight, it might be hit by a lightning stroke during thunderstorms [1]. When that happens, the lightning current flows along the surface of the aircraft affecting the aircraft. Either the surge current or the magnetic field created by the surge current can penetrate the fuselage through an aperture or by diffusion through the aircraft skin that can cause electromagnetic (EM) interference with on-board electronics. At the High Power Laboratory of the Wright-Patterson Air Force Base (WPAFB), an aluminum test cylinder, representative in size and construction of an aircraft fuselage, was subjected to high surge currents, up to 15 kA. Transient magnetic flux density (dB/dt) measurements were conducted outside and inside the test cylinder at various test points.

The susceptibility of airborne vehicles to EM transients has been studied for many years [2, 3]. Knowing the magnetic flux density (B) distribution inside when the surge current flows through the fuselage can be helpful in evaluating the EM compatibility performance of the airborne equipment.

The main objective of this paper is to describe the test setup used for surge current and dB/dt measurements along the test cylinder, and to present some of the measurement results.

II. HIGH POWER TEST FACILITIES

The High Power Laboratory of the Air Force Research Laboratory (AFRL) at WPAFB has a surge current generator (up to 20 kA discharge currents), an aluminum test cylinder simulating an aircraft fuselage, a shielded room, and data acquisition system.

For the tests, a coaxial arrangement was prepared to investigate the effects of inside magnetic field sources such as a conductor carrying a large current inside the full-length cylinder.

The test setup consists of the test cylinder, and a high voltage cable without its shield. The test setup is shown in Figure 1. The back-end connections of the cylinder can be seen in Figure 2.

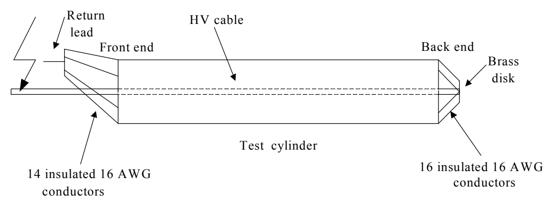

Figure 1. Test setup.

The aluminum test cylinder is fabricated from 0.125 inch thick aluminum sheets. Both ends are closed. The cylinder is 0.965 m (38 in) in diameter, 9.754 m (32 ft) long, and it consists of 4 sections. For the simulation of access panels, 16 panels, 0.61 m by 0.38 m (24 in by 15 in), are available along the cylinder.

There is a large bank of capacitors that provides the discharge current pulse. This capacitor bank is connected to the center conductor. The current return path is the cylinder itself.

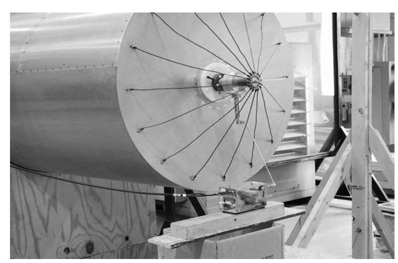

Figure 2. Rear view of the test cylinder.

III. dB/dt MEASUREMENTS

For the measurement of the dB/dt inside the test cylinder, the test setup shown in Figure 3 was prepared. By using a fiberglass arm between the center conductor and the edge of the window a bridge was made on

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which to place the probes. This fiberglass bridge was positioned at the center line of #7 of the 16 windows. Four measurement locations were marked on the bridge, with a distance 15.2 cm (6 in) between adjacent measurement points. Position 1 was directly above the center conductor, and Position 4 was near the edge of Window 7. The bridge is shown in Figure 4.

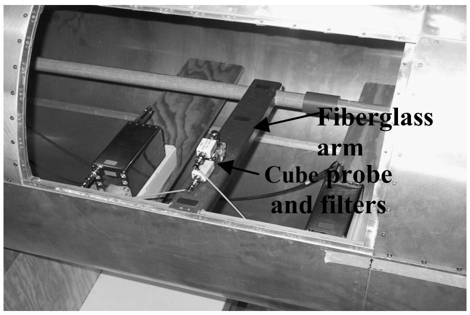


Figure 3. dB/dt test setup on the bridge at Window 7.

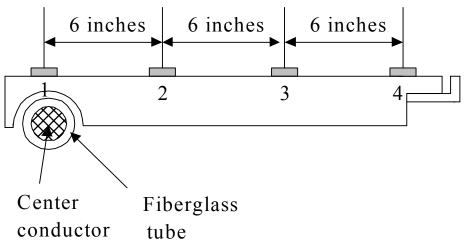


Figure 4. Bridge and probe positions.

For the inside measurement series at the center line of Window 7 a dB/dt probe was placed onto the bridge at four locations shown in Figure 4. One of the coils of a dual coil dB/dt probe was used for these measurements. Depending on the signal level, appropriate attenuators were added to the circuit.

At the same time another dB/dt probe was placed at the center line of Section 7 on the top of the outside surface of the cylinder. This probe location was not changed during the tests. One of the coils of this probe was used for the measurement of the outside dB/dt. The plane of the coil was axial and vertical.

The inside probe was attached to Positions 1 to 4, respectively, and each time the outside and inside probe outputs were saved. The entire measurement series was repeated for the closed aperture (window) case as well.

The current maximum values were around 7 kA. The maximum values of B at the outside point were around 1,700 mG. In terms of zero-to-maximum times and tail times the results were in good agreement.

To investigate the aperture effects a test setup shown in Figure 5 was prepared. For that purpose it was decided to use both coils of a dual coil probe for the inside dB/dt measurements.

Also, to study the effect of different aperture (window) cover panel materials, a window cover made of a resistive composite material (about 100 ohms/sq. surface resistivity) was prepared for the measurements. By using either the original aluminum or the resistive composite panel at the same location, the effects of open window, aluminum panel and composite panel on the dB/dt distribution were measured.

During these measurements, the fiberglass bridge was positioned at a 22.5 degree angle from the horizontal edge of Window 7 (Figure 5). A dB/dt probe was placed at the end of the fiberglass bridge. By using two test coils, i.e., two orthogonal coils of the same dual coil dB/dt probe, two components of the dB/dt were measured. Again, to monitor the outside magnetic flux density, a dB/dt probe was left attached to the top of the cylinder at the center line of Window 7.

During these tests the current maximum values were again around 7.3 kA. Table 1 gives the measurement results for these test series. The maximum B values calculated from outside dB/dt measurements were around 1,800 mG for the open aperture.

When the resistive composite panel covered Window 7, practically no change in the maximum outside B values was observed. In other words, using that particular composite material panel did not result in any change of B outside the test cylinder. However, when an aluminum panel covered Window 7, the maximum outside B values decreased significantly. The B values were around 500 mG.

For the outside dB/dt probe the dominant magnetic field source was the center conductor and the magnetic field was extended to the outside area through the open aperture, Window 7. When the aperture panel was closed the maximum B values were reduced.

For the inside measurements the situation was the opposite. Using a resistive composite panel on Window 7 did not change the inside dB/dt measurement much. When using an aluminum panel, though, the maximum value of the inside magnetic flux density increased because closing the window kept the magnetic flux lines inside the cylinder, increasing the maximum B value at that point.

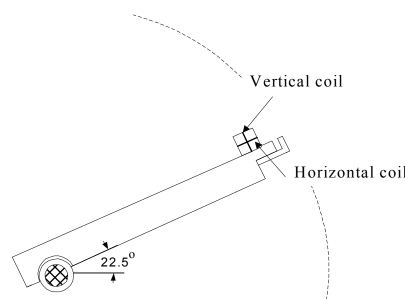


Figure 5. Inside test setup, both probe coils used.

Table 1. Outside and inside B measurement results.

Cover of Window #7	Inside dB/dt Coil	I max (A)	B_{out} max (mG)	Inside Vert. B max (mG)	Inside Horiz. B max (mG)
Open	Vert.	7,522	1,850	66,000	
Open	Horiz.	7,384	1,858		86,000
Composite	Horiz.	7,260	1,830		78,000
Composite	Horiz.	7,384	1,818		84,000
Aluminum	Horiz.	7,316	530		110,000
Aluminum	Vert.	7,178	520	77,000	
Composite	Vert.	7,316	1,906	64,500	
Open	Vert.	7,248	1,740	65,500	

Later on the inside bridge measurements (see Figure 3) were repeated for a new measurement series. The same test setup, shown in Figure 4, was used. Measurement results are given in Table 2. The dB/dt measurements were conducted at Window 7.

For the outside dB/dt measurements a probe was attached to the top of the test cylinder, at the center line of Window 7, and the plane of the dB/dt probe coil was vertical. For the inside dB/dt measurements a probe was attached to the fiberglass bridge at each one of the four marked positions, in order to determine the B vs. time at these points; the plane of the dB/dt probe was horizontal (or close to horizontal), in order to pick up the maximum component of dB/dt. The measurements were repeated for open window and closed window.

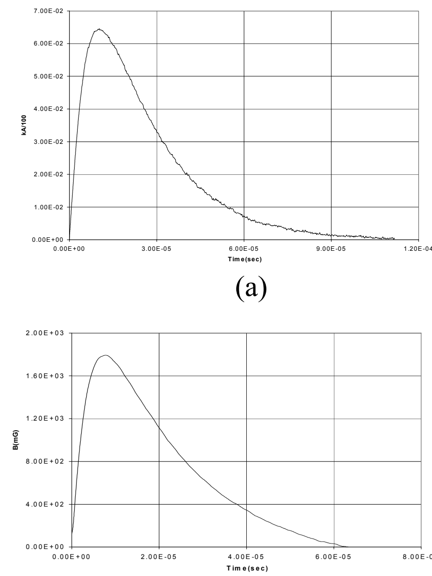
Table 2 shows the test results of current and outside B maximum values and zero-to-maximum times for the current and for B outside, for open window and closed window (with aluminum window panel) cases.

Table 2. Evaluation of test results.

Window #7	I max (A)	B_{out} max (mG)	t_{max} of I (μs)	t_{max} of B_{out} (μs)
Open	6,426	1,440	9.8	7.2
Closed	6,456	520	9.9	7.6
Open	6,448	1,680	10.2	7.8
Closed	6,518	540	9.9	8.0
Open	6,516	1,700	10.3	7.5
Closed	6,518	NA	10.1	NA
Open	6,516	1,760	9.8	7.2
Closed	6,578	480	9.8	6.7

The current maximum values were around 6.5 kA; the maximum values of the outside B were around 1,400-1,800 mG, similar to values obtained during previous experiments. One of the results was that closing the aperture (Window 7) reduced the maximum value of the outside B significantly.

Figure 6 shows an example for the processed current wave shape and for the calibrated outside B vs. time curve as well. When the current maximum value was about 6,500 A, the corresponding outside B at the top of the cylinder at the center line of Section 7 was in the vicinity of 1,800 mG. The wave shapes are in good agreement in terms of zero-to-maximum and tail times.



(a)

(b)

Figure 6. An example: (a) Processed current data. (b) Corresponding calibrated outside B vs. time.

Numerous dB/dt measurements were conducted inside the test cylinder. Their analysis will be reported in another paper.

IV. HIGH VOLTAGE LAB TESTS

The High Voltage Laboratory of The Ohio State University (OSU) has a voltage surge generator capable of up to about 1000 kV. Various experiments were conducted at OSU related to the calibration of measurement devices, investigation of the dB/dt probe performance, and simulation of the test setups at AFRL. In addition to these, in order to prepare for measurements on the actual test setup at AFRL, a model of the test cylinder setup, significantly smaller in size, was built at OSU. This small test setup was useful since various procedures and techniques were tested for several measurement problems relevant for the full scale tests at AFRL. These preliminary studies were necessary to get more accurate results and save time during the full scale test cylinder measurements.

A steel test cylinder, 152.4 cm (5 ft) long and 30.5 cm (12 in) outside diameter, was employed for these test series. In addition to the difference in sizes, an aperture (window) with a metal lid was used for this coaxial arrangement. The lid was also made of steel. The window was at the middle of the cylinder. The window size was about 30 cm long and 15 cm wide. To investigate the performance of composite materials, a

panel, with the same dimensions as the steel aperture cover, was made of the resistive composite material mentioned earlier, sprayed onto a flexible PVC sheet. Using removable covers enabled the operator to install the inside dB/dt measurement devices easily, as well as to simulate the aperture effects observed on the test cylinder at AFRL. The cylinder had two removable end caps. There is an opening on the front cap for the fiber optic cable, used for the data acquisition system.

To monitor the magnetic flux density inside and outside the coaxial test arrangement, a test setup was prepared which is shown in Figure 7. The center conductor inside the cylinder was energized at the front end, and was connected to the cylinder at the back end cap. The cylinder was the return path; it was grounded at the front end.

Figure 7 (a) shows the front view, and (b) shows the side view of the 12-inch test cylinder at OSU.

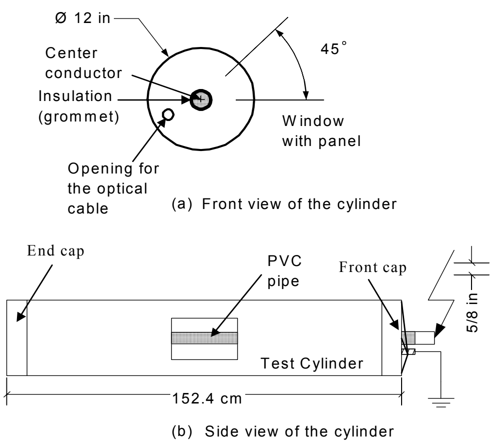


Figure 7. 12-inch test cylinder with window and its connection.

To insulate the center conductor from the front cap an insulating grommet was used. The center conductor was inside a PVC pipe. For the inside dB/dt measurements a probe was attached onto a cardboard bridge placed between the center conductor and the edge of the window. The plane of the probe coil was aligned with the center conductor. As an example of the test results, when the probe was at 114 mm distance from the center conductor, corresponding current and processed B vs. time functions at that particular measurement point are given in Figures 8 and 9.

V. CONCLUSIONS

By using a coaxial test setup, transient current and dB/dt measurements inside and outside an approx. 10 meter long and 1 meter diameter aluminum test cylinder were conducted.

The dB/dt test results were processed successfully at various test points.

B vs. time functions were derived based on dB/dt measurements. The measured current and calculated B vs. time wave shapes show very good correspondence.

Measurements of the dB/dt for various aperture (window) covers showed that using a resistive composite panel as a fuselage window cover instead of leaving the window open hardly changed the outside and inside dB/dt measurement results.

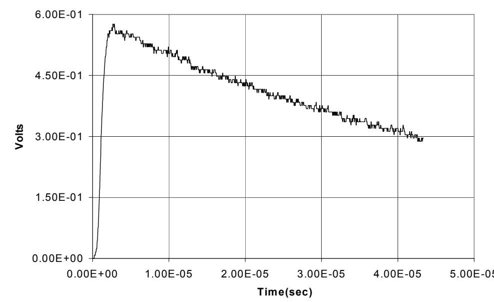


Figure 8. Surge current output.

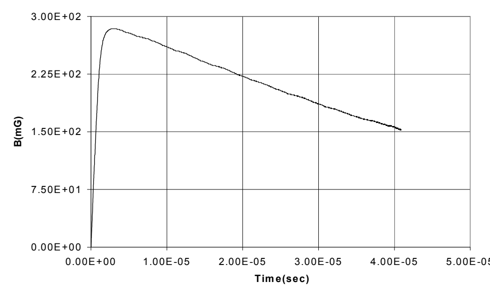


Figure 9. B vs. time function.

VI. ACKNOWLEDGMENTS

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